Hybrid Electric Vehicles– Energy Storage Technologies

The principal energy storage devices being considered for application with hybrid electric vehicles (HEVs) include high specific power/high power density batteries, flywheels, and ultracapacitors. Other technologies, such as hydropneumatic and superconducting magnetic energy storage, have been investigated; however, at this time both of these technologies are considered less promising than batteries, flywheels, or ultracapacitors for light-duty HEV application.

Batteries

No current battery technology has demonstrated an economically acceptable combination of power, efficiency, and life cycle. Developing accurate methods of determining the battery state of charge is another technical challenge, as is recyclability. Desirable HEV battery attributes include a low self-discharge rate, high charge acceptance to maximize regenerative braking utilization, and long cycle life.

Lead-acid batteries are the forerunner technology, and are currently used in commercially available electric vehicles (EVs). The basis for selection is low cost, high reliability, and an established recycling infrastructure. However, problems including low energy density, poor cold temperature performance, and low cycle life remain an impediment. High power, bipolar lead-acid batteries are being specifically developed for HEV applications.

Nickel-cadmium batteries are used routinely in communication and medical equipment and offer reasonable energy and power capabilities. They have a longer cycle life than lead-acid batteries and can be recharged quickly. The battery has been used successfully in developmental EVs. The main problems with nickel-cadmium batteries are high raw material costs, recyclability, the toxicity of cadmium, and temperature limitations on rechargeability.

Nickel-metal hydride batteries are currently used in computers, medical equipment, and other applications. They offer energy and power benefits and their components are recyclable. The main challenges with nickel-metal hydride batteries are their high cost, the high temperature they create during charging, the need to control hydrogen loss, and their low cell efficiency.

A significant amount of domestic advanced battery research is performed under the auspices of the U.S. Advanced Battery Consortium (USABC), a cost-shared effort between the major three automakers and the U.S. Department of Energy (DOE). A near-term focus of this activity is developing battery technology to support the market introduction of zero-emission electric vehicles in California and other areas.

Most of USABC's battery development activities have been related to EV development and are unsuitable for HEV applications because of their focus on high-energy storage technologies. Recently, the USABC has undertaken an expanded role in research and development of high specific power/high power density energy storage specifically for HEV propulsion systems.

Flywheels

Flywheels are devices for storing kinetic energy within a rapidly spinning wheel-like rotor or disk. Flywheels could ultimately store amounts of energy comparable to batteries. They contain no acids or other potentially hazardous materials. In addition, they are not affected by extremes of ambient temperature, as are most batteries.

Flywheels have been used in various forms for centuries, and have a long history of involvement in automotive applications. Early cars used a hand crank connected to a flywheel to start the engine, and all of today's internal combustion engines use a flywheel to store energy and deliver a smooth flow of power from the abrupt power pulses of the engine.

Modern flywheels employ a high-strength composite rotor which rotates in a vacuum chamber to minimize aerodynamic losses. A motor/generator is mounted on the rotor's shaft both to spin the rotor up to speed (charging) and to convert the rotor's kinetic energy to electrical energy (discharging). A high-strength containment structure houses the rotating elements and low-energy loss bearings stabilize the shaft. Interface electronics are needed to convert the alternating current to direct current, condition the power, and monitor and control the flywheel.

Flywheels for HEV applications must ultimately provide higher energy densities than what is presently available. In addition, their current cost is prohibitively high.

There are several concepts for using flywheels in HEVs, all of which exploit the ability to deliver very high power pulses. One concept combines a flywheel with a standard engine, providing a power assist. Another concept employs a flywheel to load-level chemical batteries. Still another uses a large or multiple flywheels to replace chemical batteries entirely. In some usages, a flywheel is referred to as an "electromechanical battery."

Recent assessments of flywheels for HEVs have concluded that the technology has advanced to the point where additional development activity might make practical devices for vehicular application available. Flywheel capabilities for practical HEV use include specific energy of approximately 100 watt-hours/kilogram, 1,000 watts/kilogram specific power, system efficiency of up to 95%, and useful life up to 1,000,000 cycles. These capabilities are all equal to or higher than current HEV battery development goals.

Ultracapacitors

Ultracapacitors are higher specific energy versions of electrolytic capacitors, devices which store energy as an electrostatic charge. They are electrochemical systems which store energy in a polarized liquid layer at the interface between an ionically conducting electrolyte and a conducting electrode. Energy storage capacity increases by increasing the surface area of the interface; R&D efforts are working to optimize this surface area.

Ultracapacitors are being developed as a primary energy device for power assist during acceleration and hill climbing, as well as recovery, of braking energy. They are also potentially useful as a secondary energy storage device in an HEV, providing load-leveling power to chemical batteries. Current R&D revolves around creating ultracapacitors with capabilities of 5Wh/kg and 1,000W/kg.

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